**What is Light?**

**Christian Huygens (1650)**

* waves travel in straight lines, too
* waves reflect off surfaces
* light refracts, it must be a wave

**Problems**: If light is a wave, it must show **interference**. It should also be able to **diffract** (bend around corners).

**Newton (1700)**

* Light travels in straight lines
* Light reflects off surfaces
* Light does not diffract
* Light does not show interference
* Light is a particle, not a wave.

**Problems**: Particles do not **refract** (bend when it enters a new medium) the way light does. Also, white light is split into colours by refraction. Newton assumed that this meant that blue light particles had more **mass**, than red light, making blue light bend less. However, he was unable to find any evidence that light had mass.

**Young (1800)**

* demonstrated that light does diffract (spread out) when passing an edge or a small opening
* showed that light interferes with itself
* Light is a wave, after all!

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Wave Property? | Particle Property? | Does light do this? (1700) | Does light do this? (1800) |
| Rectilinear Propagation | Yes | Yes | Yes | Yes |
| Reflection | Yes | Yes | Yes | Yes |
| Refraction | Yes | No | Yes | Yes |
| Diffraction | Yes | No | No | Yes |
| Interference | Yes | No | No | Yes |
| Polarization | Yes | Maybe | Yes | Yes |
| Has mass | No | Yes | No | No |
| Travels through empty space | No | Yes | Yes | Yes |
| Conclusion: |  |  | Inconclusive | Light is a wave (7 to 1) |

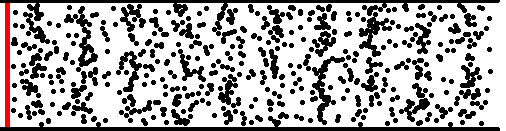
**Light - a Mediumless Wave**

By 1800, through the experiments of Young and others, it seemed clear that light is a wave.

There was still one mystery to solve: if light is a wave, it is puzzling that it can travel through space. Space is nothingness. Sound cannot travel through space. We cannot hear the sun. But light can travel through space. Also, sound travels fastest through solid materials. Yet light travels faster through less dense media, like air. Unlike sound, light slows down in solids like glass and plastic.

Recall that sound is a longitudinal matter-wave, where molecules bump into each other in sequence.

This is an animation of a sound wave. <ctrl> + click on picture to get the animation:

[](http://ffden-2.phys.uaf.edu/212_fall2003.web.dir/dennis_jackson/Lwave.g)

Molecules that are closer together (as in a solid) will transmit the wave faster through the medium. Molecules that are farther apart (as in a gas) will transmit the wave slower through the medium.

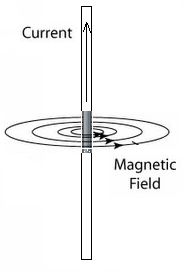
**The Aether**

To many scientists in the 1800s, the idea that light could be a wave that needed no medium was difficult to believe. Many scientists believed that light was a matter-wave like sound and space itself was a medium they called “the aether”. The aether would have to be transparent. It would have to be extremely dense so that light could travel as fast as it does. And yet, it would have to be a frictionless liquid so that the planets could flow through it. It would also be present everywhere, not just in space but here on earth, in every nook and cranny, so that light could travel in any vacuum created on earth. And finally, since Earth is travelling through it, we would expect light on Earth to travel faster in one direction and slower than another.

The complications that an aether presented to scientists made it difficult to believe that such a thing could exist. But scientists preferred to believe in the aether than to believe that light traveled without a medium. It took a number of new developments to change that thinking. One of those developments took place not in the study of light, but in the study of electricity and magnetism.

**The connection between Electricity and Magnetism**

1. A current in a wire will create a magnetic field that runs perpendicular to the current. In grade 11 you learned the right hand rule that says as much:



A compass placed behind this wire would point to the left <--

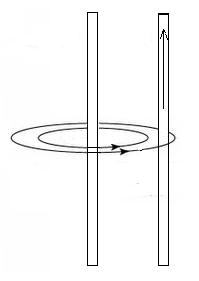
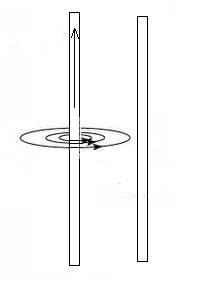
A compass placed in front of this wire would point to the right -->

1. The further away from the wire, the weaker the magnetic field gets, according to the inverse square law.
2. If a wire has no current in it and then suddenly has a current in it, a magnetic field will be produced. A nearby compass will deflect (point in a particular direction) in response to this new magnetic field. But does this happen instantly, or does it take time for the field to spread out into space, like ripples in a pond?

James Clerk Maxwell put together all the equations known at the time regarding electricity and magnetism. Putting them together he found the speed of the magnetic field, which he calculated to be 3.0x108m/s. He immediately recognised that number to be the speed of light.

The spreading magnetic field is not a “wave” in the normal sense. It is a field that takes time to propagate. The fact that it spreads at a certain speed is a curiosity; why it goes at this speed, no one knows. But the number 3.0x108m/s seems to be a constant of nature.

1. **Induction**: If a pulse of current is sent through a wire, and a second wire is placed in the path of the magnetic field that ripples outward, a pulse of current will be induced in the second wire.

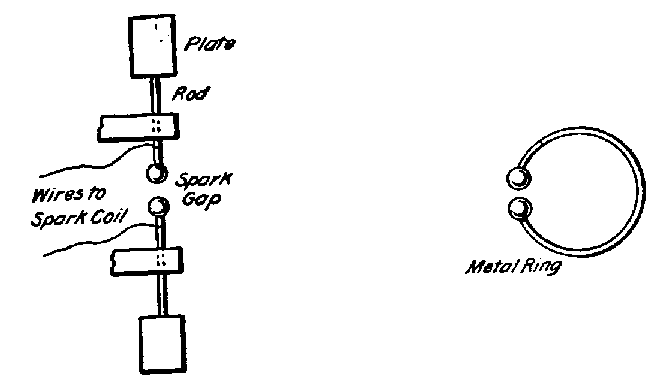


A current in the wire on the left sends an electromagnetic pulse

When the pulse reaches the wire on the right, a current is created. Notice that the first wire no longer has current.

An [electromagnetic pulse](http://videos.howstuffworks.com/discovery/7102-electromagnetic-pulse-bomb-video.htm) (EMP) is an example of this phenomenon. (ctrl-click to try the link!)

Inspired by Maxwell’s ideas, Heinrich Hertz set about to demonstrate this phenomenon in 1886. He set up two wires, at opposite ends of a room, and created a strong pulse of current in one wire, and then observed a current induced in the second wire. To see the current, he used a spark gap transmitter. The pulse in the first wire (transmitter) created a spark. The second wire, bent into a loop with a small gap remaining, also sparked at the same time, even though it was not connected to a power source. Hertz had invented the first radio transmission.

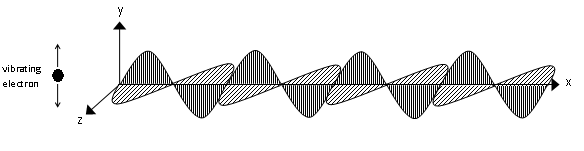
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The first application of Hertz’s invention was the wireless telegraph. The telegraph, which uses dots and dashes, could send information freely without the use of cable wires connecting telegraph stations. Soon after the wireless telegraph came radio, which runs on the same principle. A radio antenna is essentially the second wire.

**Light as an electromagnetic wave**

So what is light? It is an electromagnetic wave. Such a wave is produced anytime an electron is induced to move. Although radio uses current in a wire, any moving electron can be the “current” needed to produce the magnetic field. In this sense, any electron can be a transmitter or a receiver.

If the electron is sent back and forth – oscillating – then the magnetic field will oscillate also. An oscillating magnetic field will produce an oscillating electric field, which would induce another electron anywhere in the path of the magnetic field to oscillate as well:

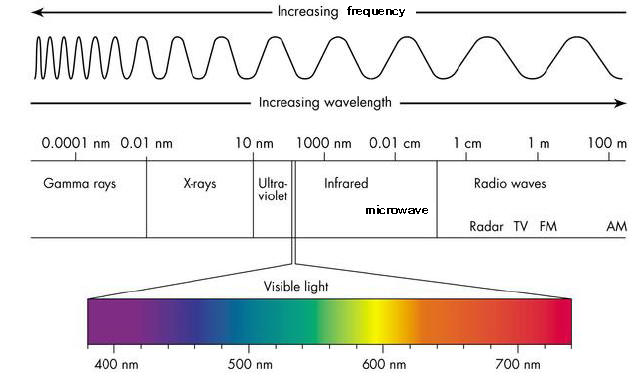


In this picture, an electron is moving up and down in the y direction. This creates a magnetic field that acts in the z plane (in other words, a compass placed on a table would deflect). Since the electron is oscillating (changing direction), the magnetic field also changes direction (the compass would flip back and forth). The pulse travels away from the source at the speed of light.

**The EM spectrum**

short wave

long wave



Violet

Red

The frequency of the oscillations are directly connected to the wavelength of the wave. If the frequency is low, the waves are long. Radio waves are long waves. They are created by moving free electrons long distances up and down a metal antenna. Radio wavelengths are measured in metres.

Microwaves are short radio waves. Microwaves do not need as long an antenna to be transmitted and received. Cell phones use microwaves. Microwaves are in the cm or mm range.

Microwaves can be used to heat water. Water molecules will resonate when exposed to waves of the right frequency.

In between microwaves and visible is the infrared range. This is the frequencies where most molecules vibrate. Molecular vibration is perceived as heat.

Visible waves are smaller still. They run in the nm range. The longest visible wavelength is red light, at 750nm, the shortest is violet, at 400nm. At these wavelengths, valence electrons bound in atoms and molecules will resonate back and forth between orbitals.

Beyond visible lies the ultraviolet rays. They are able to resonate valence electrons enough to remove them from the atom. This is called ***ionizing* *radiation***. Ionizing radiation can be harmful as it can change the chemistry of molecules, which may alter their function in a biological system.

Xrays and Gamma rays are highly ionizing, being able to remove even the inner electrons of an atom. Such rays are products of nuclear reactions, which is why radioactive materials are dangerous to humans.